REPORT ON PRELIMINARY TESTING OF OFFROAD EVAPORATIVE EMISSIONS

Introduction

This report summarizes the preliminary results of testing to quantify evaporative and permeation emissions from off-road equipment fuel tanks (OREFT). The testing is a component of an investigation into the feasibility of developing control measures to limit permeation and evaporative emissions from OREFT.

The objective of the preliminary testing was to determine baseline evaporative and permeation emissions from a typical HDPE fuel tank used in off-road equipment. We selected a one-quart Tecumseh mower fuel tank to test. The tank was selected because of its simple geometry and typical size.

In addition to determining the baseline evaporative and permeation emissions, we wanted to evaluate four evaporative emission control technologies (non-vented/ sealed tanks, tanks vented to carbon canisters, tanks retrofitted with fuel bladders, and vented tanks containing metal mesh) we identified as possible solutions to reduce evaporative emissions.

Preliminary Test Results

Our first objective was to determine the baseline evaporative emissions (excluding permeation emissions) from a representative fuel tank. After obtaining the baseline data, we measured emissions with the same fuel tank model using the four control technologies described above.

Baseline and Emission Control Testing

Table 1 summarizes the baseline and controlled evaporative emissions for a 24-hour diurnal test from one-quart Tecumseh fuel tanks in grams/day.

Table 1

Test No.	#1	#2	#3	#4	#5	#6	Mean	Std. Dev.
Vented	0.566	0.443	0.454	0.526	0.517	0.491	0.500	0.04640
Treated/Sealed	0.043	0.033	0.022				0.033	0.01050
Vented to Carbon Canister	0.015	0.024					0.020	0.00636
Containing Metal Mesh	0.375	0.646	0.534	0.598	0.545	0.512	0.535	0.09222
Containing Bladder	0.074	0.203					0.139	0.09122

An analysis of the above data was performed using the Student's t-Test with unknown and equal variances. Tables 2 –5 detail the results of the analysis.

Table 2		
	Vented	Treated/Sealed
Mean	0.500	0.033
Variance	0.00215	0.00011
Observations	6	3
Pooled Variance	0.00157	
Hypothesized Mean Difference	0.4	
df	7	
t Stat	**2.38580**	
P(T<=t) two-tail	0.04847	
t Critical two-tail	**2.36462**	

Table 3		
	Vented	Vented to Carbon Canister
Mean	0.500	0.020
Variance	0.00215	0.00004
Observations	6	2
Pooled Variance	0.00180	
Hypothesized Mean Difference	0.39	
df	6	
t Stat	**2.59735**	
P(T<=t) two-tail	0.04081	
t Critical two-tail	**2.44691**	

Table 4		
	Vented	Containing Metal Mesh
Mean	0.500	0.535
Variance	0.00215	0.00850
Observations	6	6
Pooled Variance	0.00533	
Hypothesized Mean Difference	0.035	
df	10	
t Stat	**-1.67280**	
P(T<=t) two-tail	0.12531	
t Critical two-tail	**2.22814**	

Table 5		
	Vented	Containing Bladder
Mean	0.500	0.139
Variance	0.00215	0.00832
Observations	6	2
Pooled Variance	0.00318	
Hypothesized Mean Difference	0.24	
Df	6	
t Stat	**2.62754**	
P(T<=t) two-tail	0.03919	
t Critical two-tail	**2.44691**	

Statistically significant differences (based on a comparison of the t Stat and the t Critical two-tail values) were noted for sealed tanks, tanks vented to carbon canisters, and tanks containing fuel bladders. No significant difference was noted for tanks containing metal mesh.

The following emission reduction efficiencies were calculated:

Table 6		
	Average Emissions (grams/day)	Efficiency
Vented	0.500	
Treated/Sealed	0.033	93.4%
Vented to Carbon Canister	0.020	96.0%
Containing Metal Mesh	0.535	Inconclusive
Containing Bladder	0.139	72.2%

Pressure Dependency Testing

When fuel tanks are sealed to reduce diurnal evaporative emissions, the result is a buildup of vapor pressure. A logical question is whether increased pressure will result in an increase in permeation. The pressure dependency testing was conducted to answer this question. Our basic approach was to measure the permeation rate at a constant temperature of 80 °F while varying the pressure on the gasoline. We tested eight fuel tanks in three five-day test periods at 0.0, 2.5, and 5.0 psig. Tables 7 – 9 detail the results of the testing.

Table 7 – 0.0 psig							
Tank	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Average**	**Std. Dev.**
#1	2.57	2.62	2.62	2.62	2.67	2.62	0.03536
#2	2.06	2.25	2.20	2.16	2.30	2.19	0.09154
#3	2.53	2.58	2.67	2.58	2.77	2.63	0.09503
#4					2.56	2.56	
#5	2.39	2.63	2.63	2.63	2.77	2.61	0.13711
#6*	2.72	2.86	2.77	2.82	2.77	2.79	0.05357
#7	2.48	2.72	2.67	2.63	2.72	2.64	0.09915
#8	2.76	2.99	2.90	2.95	2.86	2.89	0.08871
					Mean	*2.62*	
					Std. Dev.	*0.21877*	
					Upper 95	*2.79*	
* Control					Lower 95	*2.46*	

Table 8 – 2.5 psig							
Tank	**Day 6**	**Day 7**	**Day 8**	**Day 9**	**Day 10**	**Average**	**Std. Dev.**
#1	3.39	3.12	3.15	3.21	3.19	3.21	0.10545
#2	2.56	2.37	2.38	2.46	2.45	2.44	0.07635
#3	2.98	2.75	2.81	2.87	2.86	2.85	0.08503
#4	2.81	2.53	2.61	2.66	2.62	2.65	0.10310
#5	2.98	2.93	2.91	3.00	2.99	2.96	0.03962
#6*	2.89	2.80	2.77	2.85	2.81	2.82	0.04669
#7	3.03	2.80	2.85	2.90	2.88	2.89	0.08585
#8	3.30	3.03	3.08	3.12	3.11	3.13	0.10232
					Mean	*2.88*	
					Std. Dev.	*0.26620*	
					Upper 95	*3.07*	
* Control					Lower 95	*2.68*	

Table 9 – 5.0 psig							
Tank	**Day 11**	**Day 12**	**Day 13**	**Day 14**	**Day 15**	**Average**	**Std. Dev.**
#1	3.16	3.45	2.98	3.17	3.32	3.22	0.17785
#2	2.70	2.94	2.47	2.75	2.90	2.75	0.18674
#3	3.31	3.50	3.17	3.36	3.46	3.36	0.13058
#4	2.77	2.87	2.54	2.73	2.83	2.75	0.12814
#5	3.17	3.50	3.13	3.32	3.46	3.32	0.16622
#6*	2.89	3.13	2.66	2.90	3.00	2.92	0.17271
#7	3.11	3.30	3.03	3.17	3.27	3.18	0.11171
#8	3.21	3.49	2.89	3.17	3.41	3.23	0.23426
					Mean	*3.12*	
					Std. Dev.	*0.25722*	
					Upper 95	*3.31*	
* Control					Lower 95	*2.93*	

Table 10 compares the three test periods.

Table 10			
Tank	**Avg. Day (1-5)**	**Avg. Day (6-10)**	**Avg. Day (11-15)**
#1	2.62	3.21	3.22
#2	2.19	2.44	2.75
#3	2.63	2.85	3.36
#4	2.56	2.65	2.75
#5	2.61	2.96	3.32
#6*	2.79	2.82	2.92
#7	2.64	2.89	3.18
#8	2.89	3.13	3.23
Mean	*2.62*	*2.88*	*3.12*
Std. Dev.	*0.21877*	*0.26620*	*0.25722*
Upper 95	*2.79*	*3.07*	*3.31*
Lower 95	*2.46*	*2.68*	*2.93*

Permeation Testing

Permeation data for Tecumseh tanks were measured during the first phase of the pressure dependency testing. Data for eight fuel tanks are compared with the permeation rate of 1.57 grams/gallon/day established for portable fuel containers. Note that Tank #4 developed a leak during the testing. Tank #4 data for the first four days of testing is therefore not included in the calculation of the average permeation rate.

For every tank tested, the permeation rate is significantly higher than the average established for portable fuel containers. Assuming the permeation rate is similar for HDPE tanks in the off-road category, the average permeation emissions from a one-quart fuel tank is approximately 0.66 grams/day. Testing of additional fuel tank types is needed to validate this assumption.

Diurnal Measurements of Off-road Equipment

Limited diurnal data were also collected on four pieces of off-road equipment. For the Honda and Briggs & Stratton mowers, and the Honda trimmer, replacement fuel tanks were also tested to determine their contribution to the total emissions. The emissions measured are compared to the U.S. EPA's NONROAD emission factors in the following table:

Table 11				
	Honda Mower	**Briggs & Stratton Mower**	**Briggs & Stratton HS Engine**	**Honda Trimmer**
Measured emission factor from complete system	2.665 grams/day	2.737 grams/day	1.759 grams/day	0.787 grams/day
Measured emissions from tank only	0.515 grams/day	1.004 grams/day	**	0.144 grams/day
NONROAD emission factor	4.0 grams/day	4.0 grams/day	1.8 grams/day	0.54 grams/day

***Not measured; tank integral to carburetor.*

The emissions measured for the complete systems of the Honda and Briggs & Stratton mowers, and the Honda trimmer, included permeation emissions.

Additional Testing

Permeation

We developed our initial permeation emission estimate based on the average permeation rate determined for portable fuel containers. For Tecumseh fuel tanks, the permeation rate is significantly higher. Because of this difference, we suspect that permeation rates for fuel tanks in general may be greater than the rate for portable fuel containers. Therefore, we need to establish an average permeation rate for off-road equipment fuel tanks. We can do this by testing a variety of fuel tanks in the off-road category and averaging the results. After an average rate has been determined, it will be used to recalculate the permeation emission estimate.

The initial pressure dependency testing was performed on untreated fuel tanks at a constant temperature. The data confirmed that the permeation rate is a function of pressure. We should now test treated tanks at 5.0 psig to gauge their ability to attenuate permeation emissions.

Diurnal Emission Factors

In order to develop a defensible diurnal emission estimate, evaporative emissions need to be fully investigated. Therefore, we need to separate and quantify the components of evaporative (hot soak, running loss, and diurnal) emissions. Diurnal emissions in turn have two basic components (emissions from a carburetor and emissions from a vented cap). The end result of the investigation would be representative diurnal emission factors for the distinct categories of off-road equipment in NONROAD. After a factor has been established for each category, they will be used to refine our diurnal emission estimate.

Diurnal Emission Factor and Permeation Rate Test Plan

We intend to lease a representative piece of equipment for each of the category in NONROAD. We will also purchase two fuel tanks for each piece of test equipment. Each piece of equipment will be operated for one hour and immediately placed in a SHED for a 72-hour test period. The two tanks purchased for each piece of equipment will be used to quantify emissions vented through the fuel cap and permeation emissions from the fuel tank walls.

Testing Notes: It will be assumed that the first 24 hours of SHED data will include permeation, evaporative and hot soak emissions. It will also be assumed that the last 48 hours of SHED data does not include hot soak emissions. Diurnal emission factors will be calculated by subtracting the permeation emissions from the average of the last 48 hours of SHED data.

Determining the Vapor Loss Associated with Refueling

In order to account for vapor loss associated with refueling a fuel tank, we intend to perform the following test:

- Fill twelve one and two-gallon fuel containers that meet the new fuel container regulations to 30%, 50%, and 70% of capacity with CERT fuel.
- Soak the sealed fuel containers in a SHED for five 24-hour periods at a constant 75° Fahrenheit.
- At the end of each 24-hour period measure the vapor pressure on one of the sealed fuel containers configured with a pressure transducer.
- When the standard deviation for last three consecutive vapor pressure readings are within 0.1 (i.e., equilibrium conditions are met) weigh each fuel container with a calibrated balance accurate to within 0.01 grams.
- After the initial weighing, vent each container to ambient pressure by removing their caps. Reseal and reweigh each fuel container.

The difference in weight for each container should approximate the grams of hydrocarbons released into the atmosphere during a refueling event.

Conclusions

The following important generalizations are based on an analysis of the above test results:

- Baseline evaporative (not including permeation emissions) emissions from small fuel tanks can be expected to range from 0.1 to 1.0 gram/day.
- Isolating a fuel tank to prevent vapors from escaping to the atmosphere can significantly reduce evaporative emissions.
- Venting vapors to a carbon canister can significantly reduce evaporative emissions.
- Permeation emissions are greater (2.62 grams/gallon/day versus 1.57 grams/gallon/day) in Tecumseh off-road equipment fuel tanks when compared with permeation rates for portable fuel containers.
- Evaporative and permeation emissions from off-road equipment fuel tanks account for roughly 60% of the total system emissions.
- Testing of additional off-road equipment and tanks is needed to refine our emission estimate.